

Vertical subgrid-scale heterogeneity and cloud overlap parameterizations for low-level clouds in GCMs and RCMs

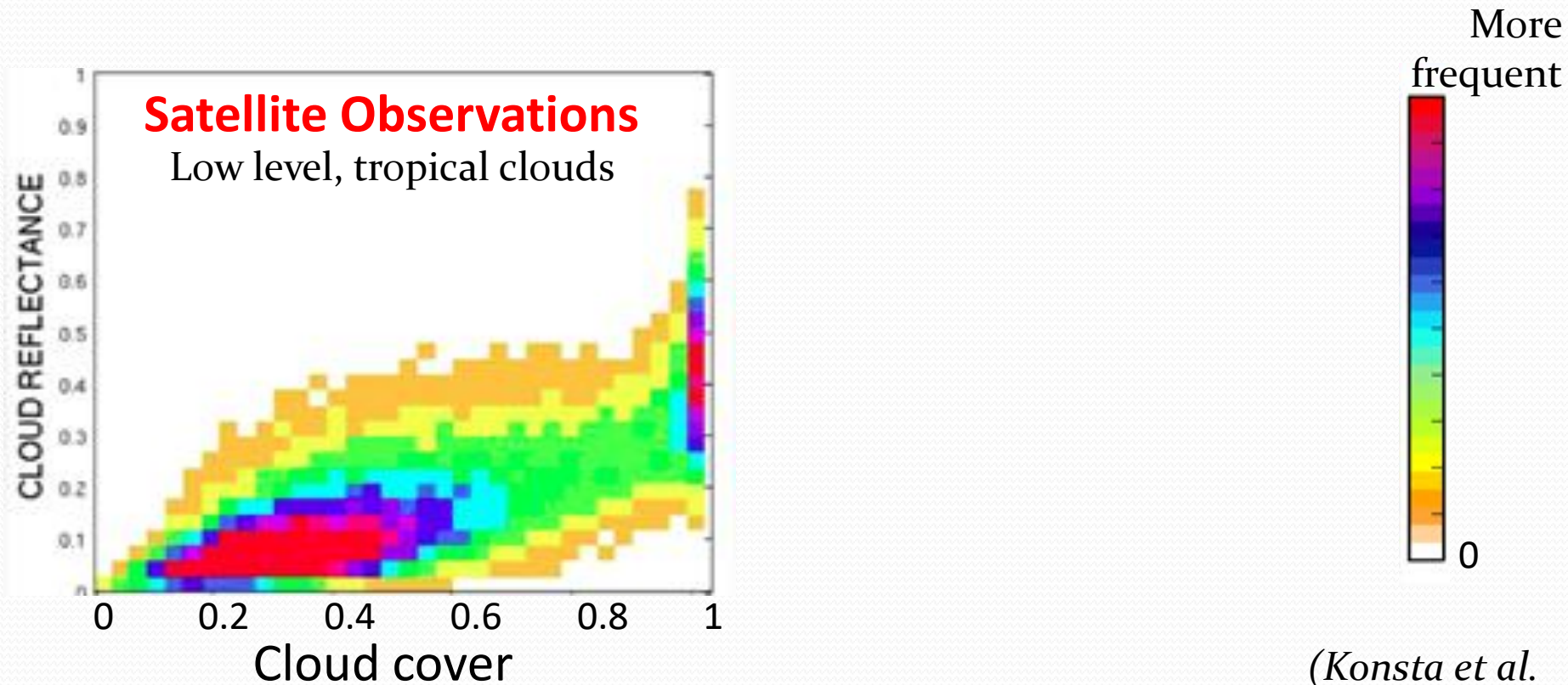
Jean JOUHAUD, Jean-Louis DURESNE, Jean-Baptiste MADELEINE

LMD/IPSL, Paris, France

CFMIP workshop, 30 Sept – 4 Oct, Mykonos, Grece

Too Few, too Bright low-clouds

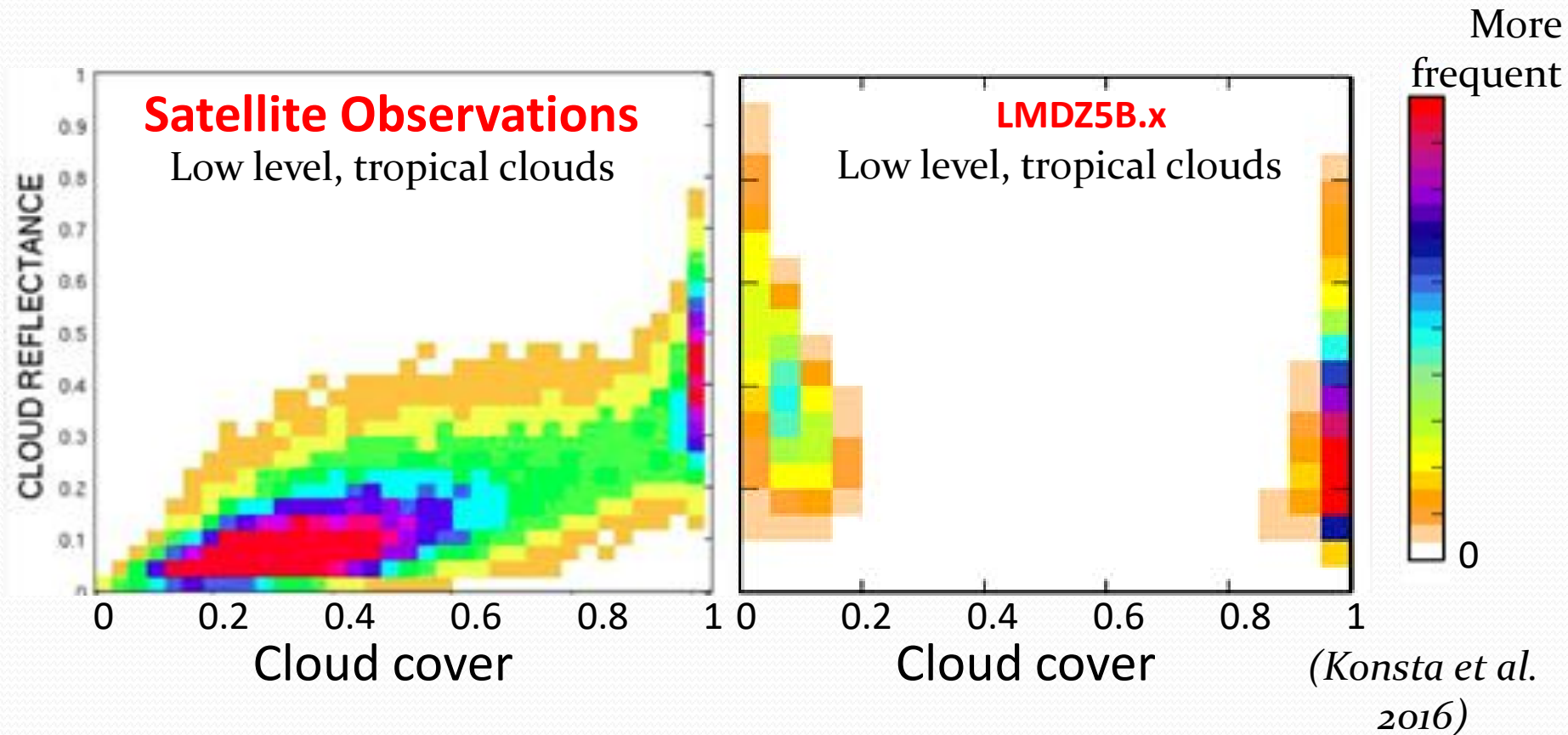
GCMs (RCMs?) simulate **cumulus** type clouds with **too small cloud fraction** and **too high cloud reflectance**.



(Konsta et al.
2016)

Too Few, too Bright low-clouds

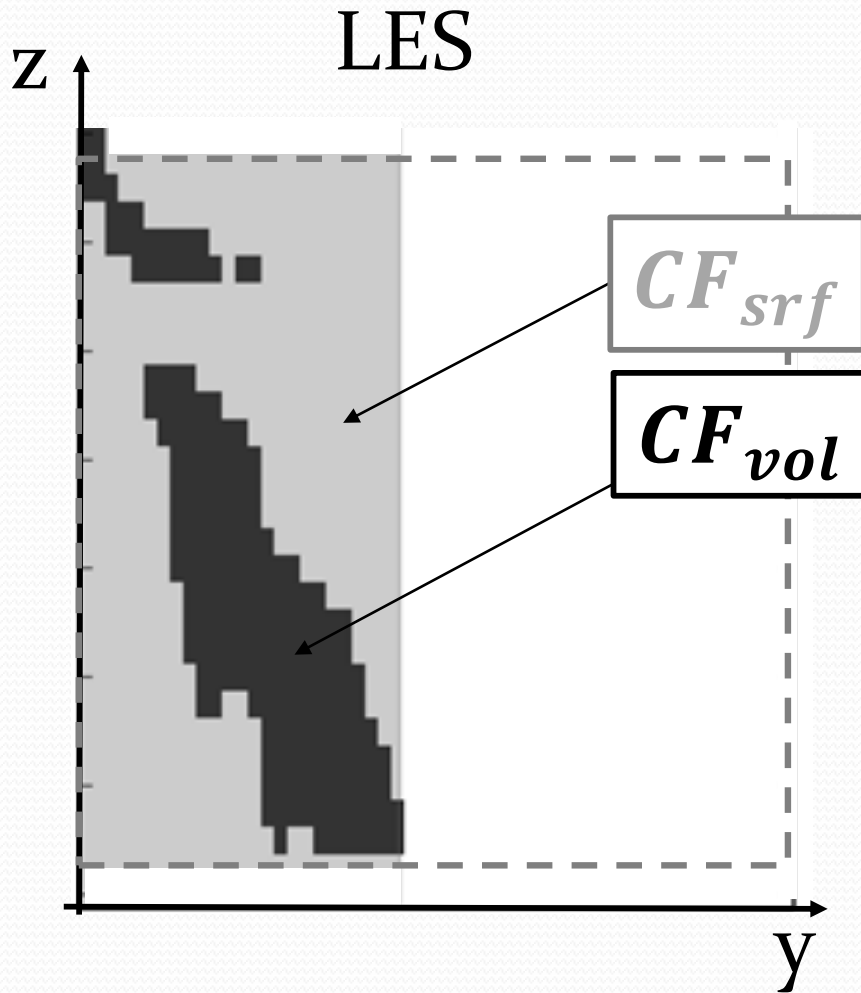
GCMs (RCMs?) simulate **cumulus** type clouds with **too small cloud fraction** and **too high cloud reflectance**.



Working hypothesis: the *vertical heterogeneity* of cloud properties is misrepresented in models

Cloud vertical heterogeneity

vertical slice of a cloud simulated by a



Two cloud fractions (CF):

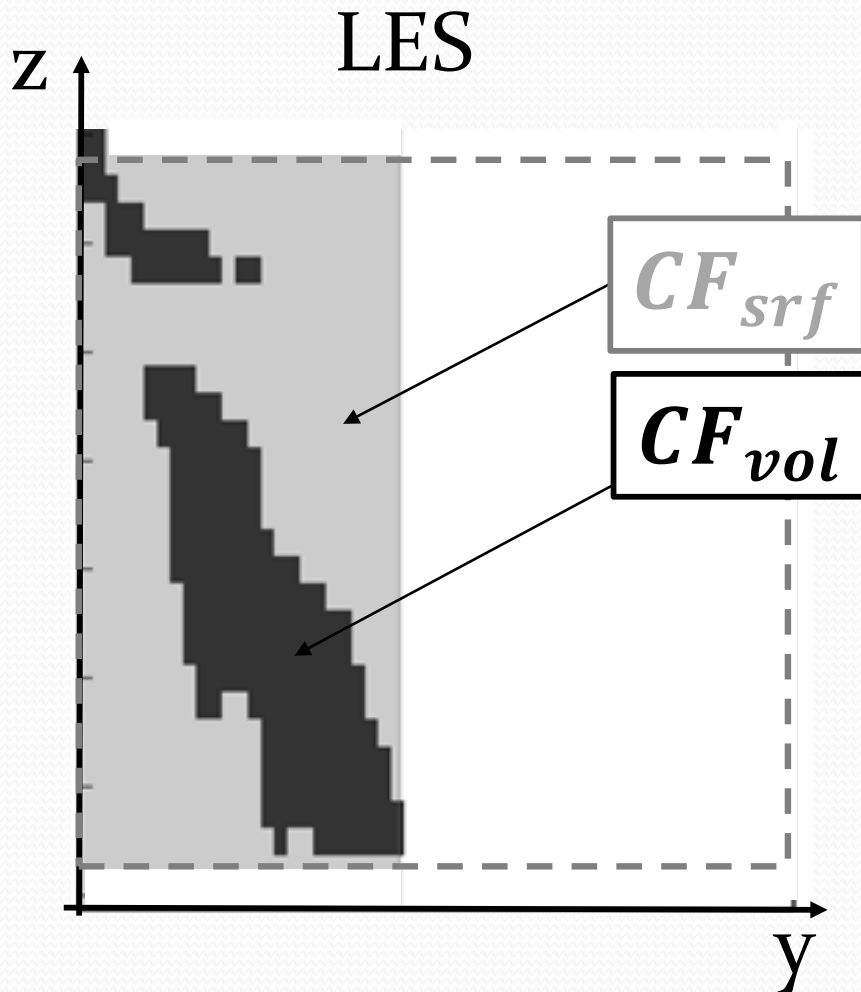
- by volume CF_{vol}
- by surface CF_{srf} (by area seen from above)

CF_{vol} : depends on
microphysics

CF_{srf} : depends on CF_{vol} and
on *vertical geometry of clouds*

Cloud vertical heterogeneity

vertical slice of a cloud simulated by a



Two cloud fractions (CF):

- by volume CF_{vol}
- by surface CF_{srf} (by area seen from above)

CF_{vol} : depends on *microphysics*

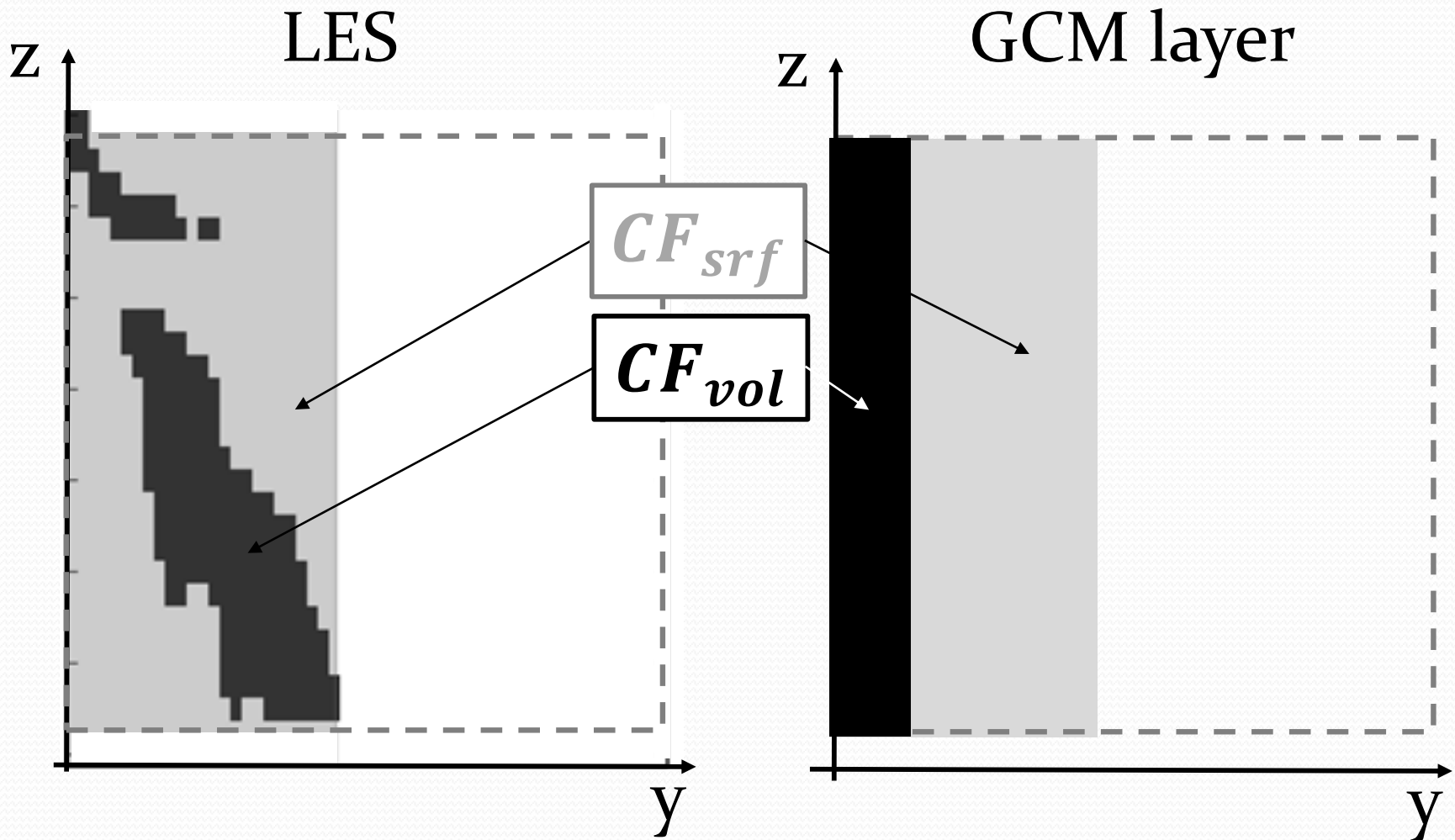
CF_{srf} : depends on CF_{vol} and on *vertical geometry of clouds*

$CF_{srf} > CF_{vol}$ but in GCM and RCM layers, $CF_{srf} = CF_{vol}$

How to correct this?

Cloud vertical heterogeneity

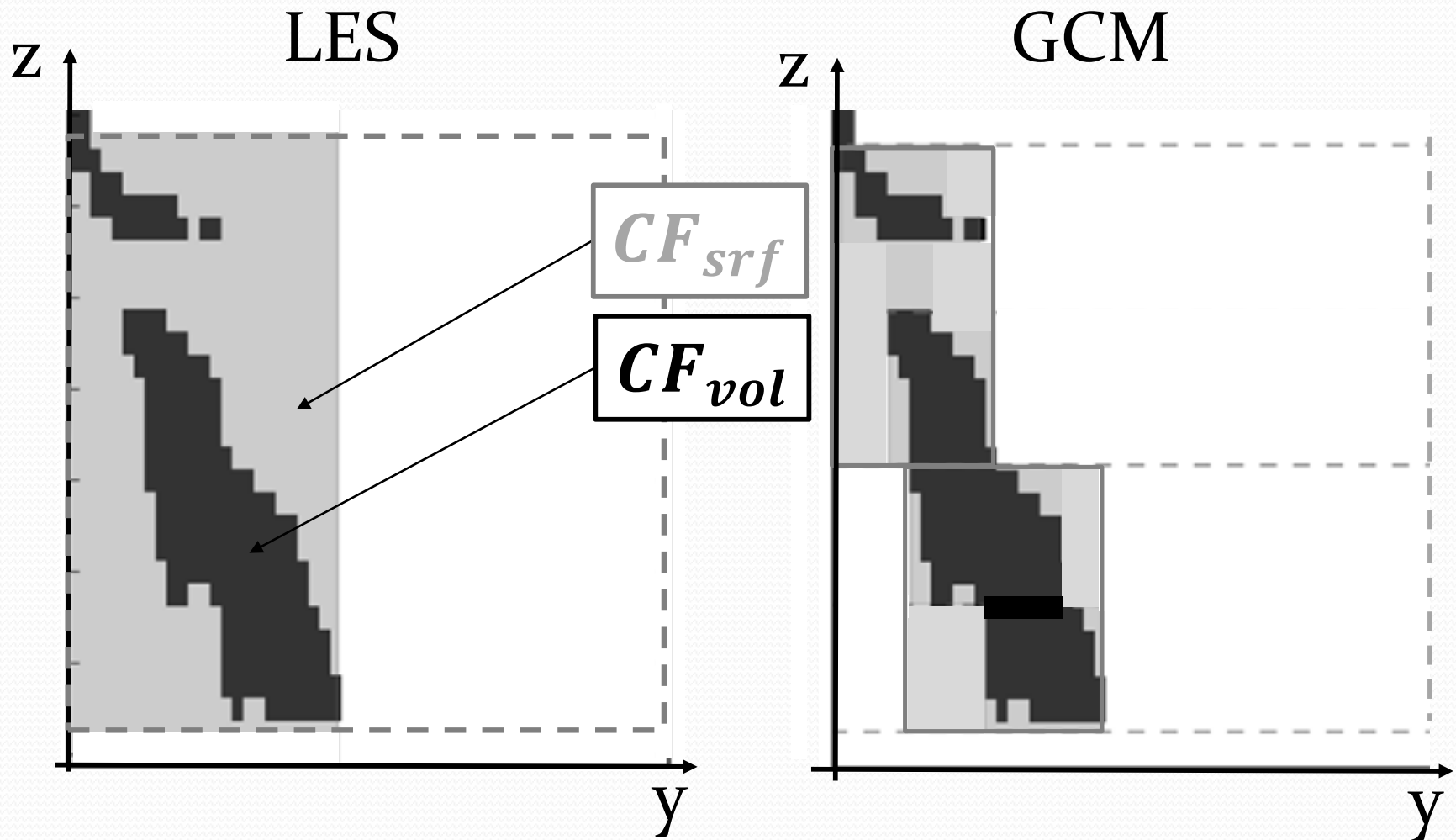
vertical slice of a cloud simulated by a



Need to introduce subgrid heterogeneity of clouds in GCMs

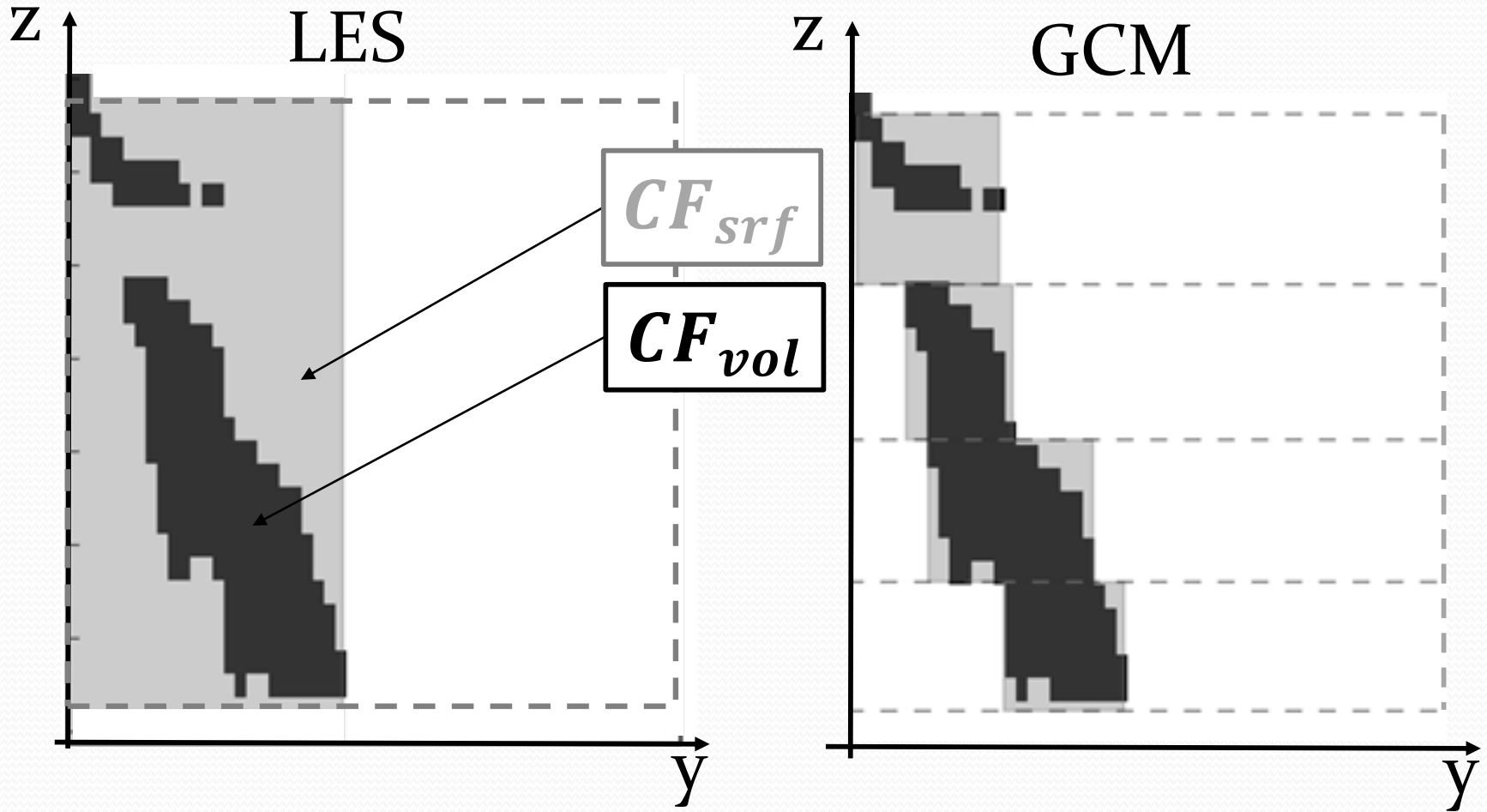
Cloud vertical heterogeneity

vertical slice of a cloud simulated by a



Cloud vertical heterogeneity

vertical slice of a cloud simulated by a



Subgrid heterogeneity and cloud overlap are intended to represent the same geometrical characteristics

1) Parameterization of subgrid heterogeneity

For **cumulus clouds**,
based on **LES simulations**

$$CF_{surf} = (1 + 0,0044 \cdot \Delta z) CF_{vol}$$

(Neggers et al. 2011, Jouhaud et al. 2018)

1) Parameterization of subgrid heterogeneity

For **cumulus clouds**,
based on **LES simulations**

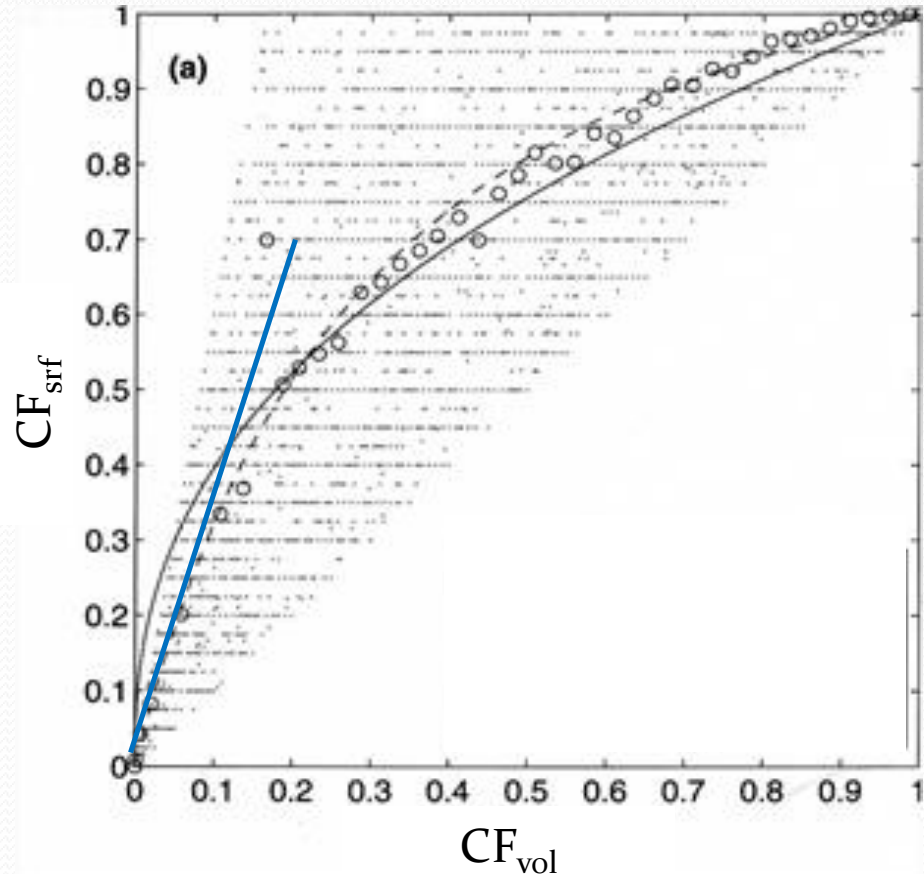
$$CF_{surf} = (1 + 0,0044 \cdot \Delta z) CF_{vol}$$

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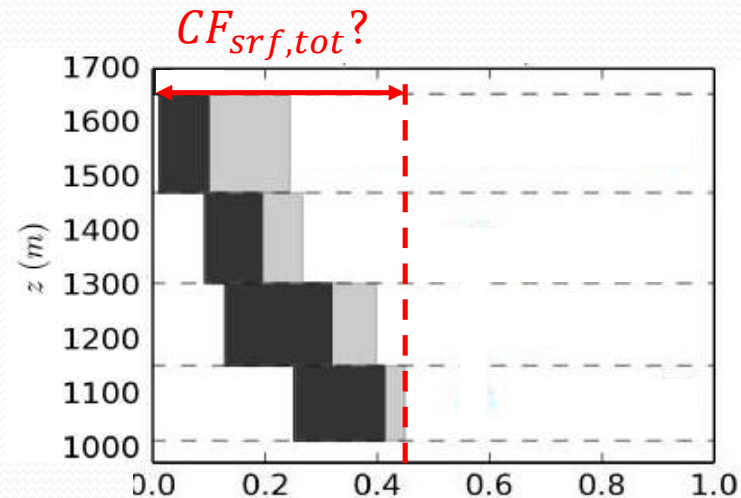
For **all clouds**,
based on **satellite observations**

$$CF_{srf} = \frac{1}{1 + e^{-f} \left(\frac{1}{CF_{vol}} - 1 \right)}$$

f depends on Δz , Δx and wind shear
(Brooks et al. 2005)



2) Parameterization of cloud overlap



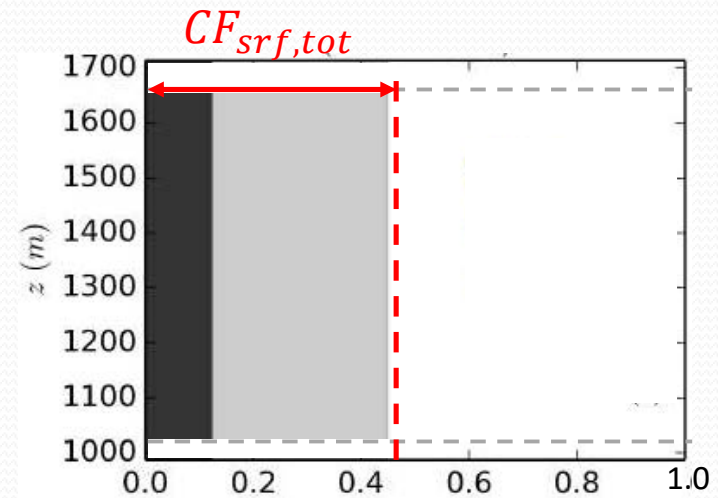
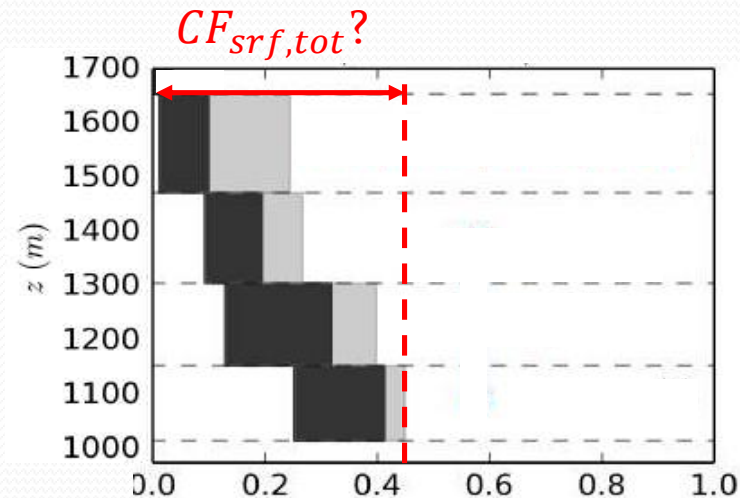
For each atmospheric layer i:

Microphysic $\rightarrow CF_{vol}(i)$

SG heterogeneity $\rightarrow CF_{srf}(i)$

$CF_{srf,tot}?$

2) Parameterization of cloud overlap



For each atmospheric layer i:

Microphysic $\rightarrow CF_{vol}(i)$

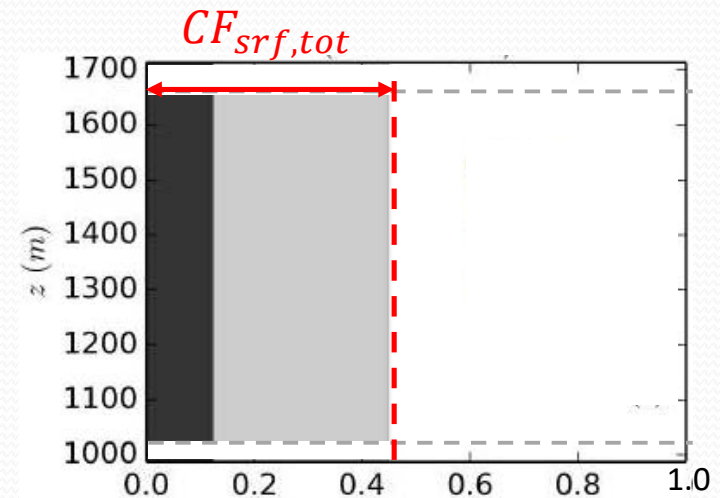
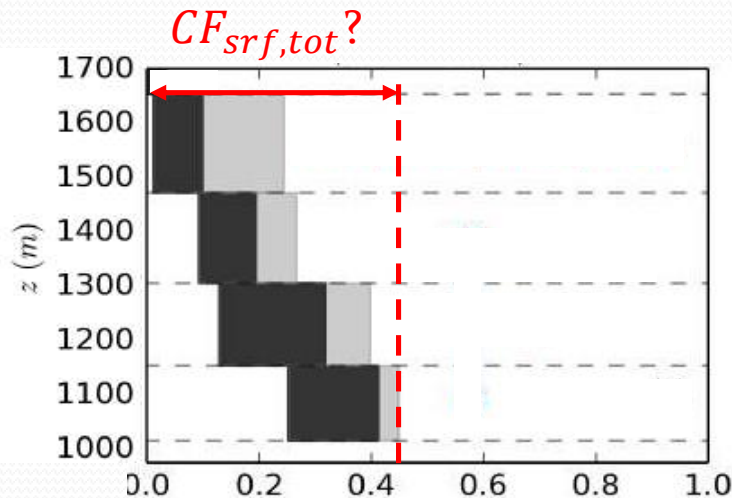
SG heterogeneity $\rightarrow CF_{srf}(i)$

For total cloud layer

$$CF_{vol,tot} = \sum CF_{srf}(i)$$

$CF_{srf,tot}$ \leftarrow SG heterogeneity

2) Parameterization of cloud overlap



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Microphysic $\rightarrow CF_{vol}(i)$

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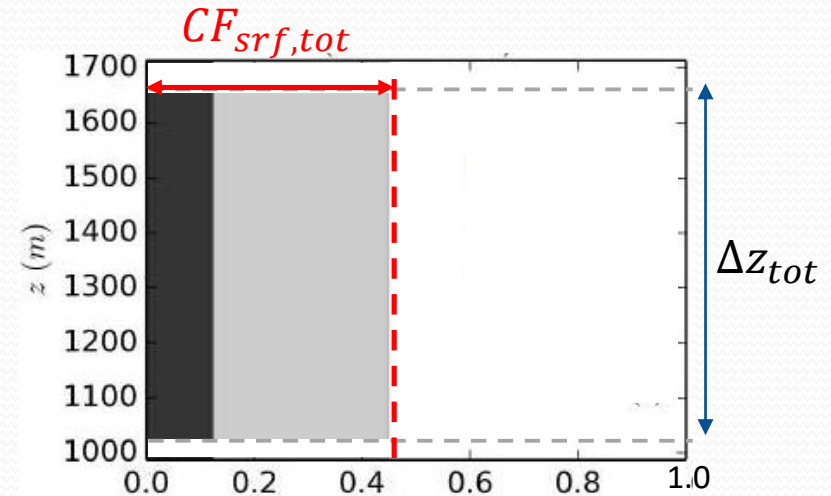
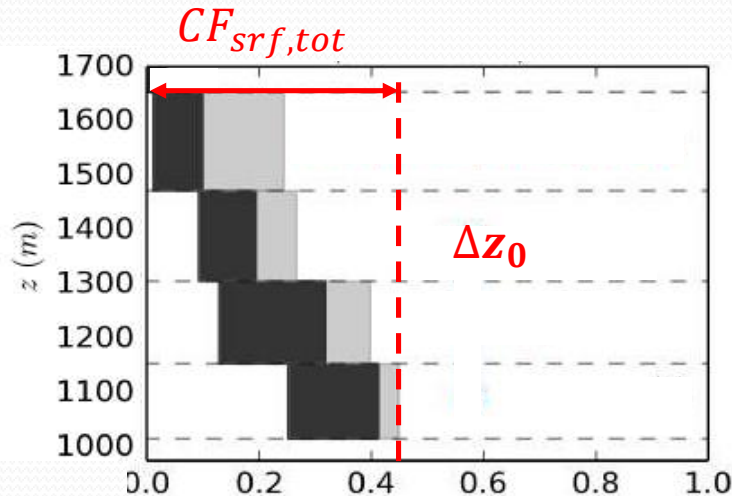
Exponential random overlap approach (Hogan & Illingworth 2000)

decorrelation length Δz_0 :

$$CF_{tot}(i,j) = \alpha CF_{max} + (1 - \alpha) CF_{random} \text{ with } \alpha = e^{-\frac{\delta z(i,j)}{\Delta z_0}}$$

Δz_0 ?

2) Parameterization of cloud overlap



For each atmospheric layer i:

Microphysic $\rightarrow CF_{vol}(i)$

SG heterogeneity $\rightarrow CF_{srf}(i)$

CF_{rand}, CF_{max}

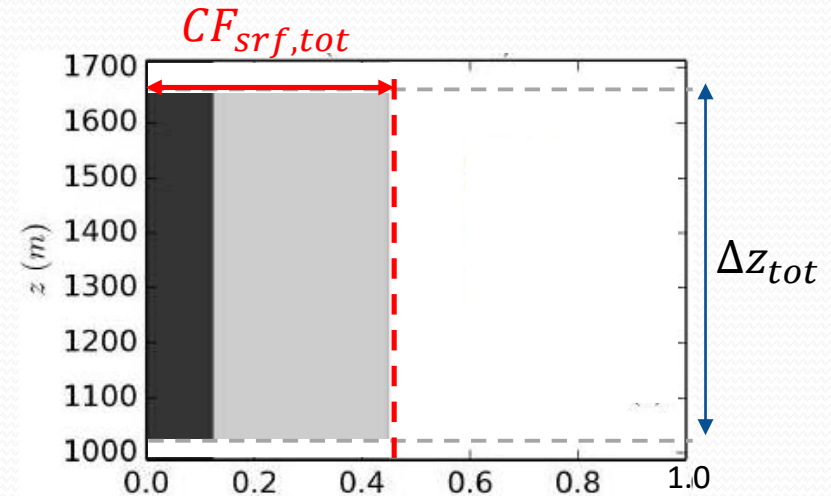
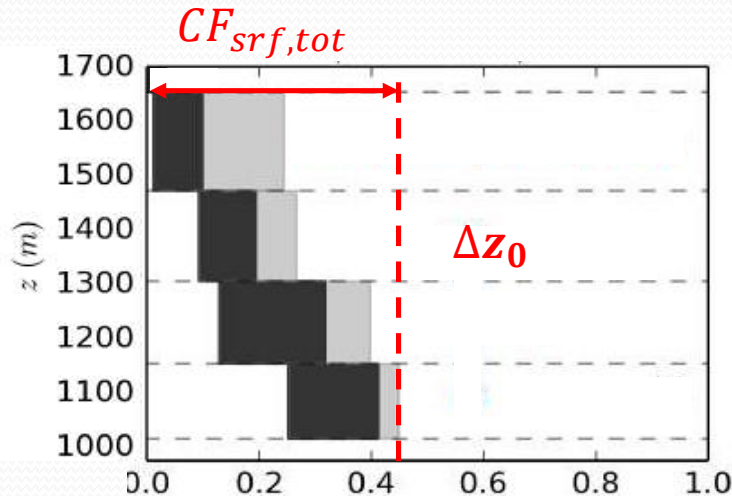
For total cloud layer

$CF_{vol,tot} = \sum CF_{srf}(i)$

$CF_{srf,tot}$ \leftarrow SG heterogeneity

$$\Delta z_0 = \frac{-\Delta z_{tot}}{\ln \left(\frac{CF_{srf,tot} - CF_{rand}}{CF_{max} - CF_{rand}} \right)}$$

2) Parameterization of cloud overlap



For each atmospheric layer i:

Microphysic $\rightarrow CF_{vol}(i)$

SG heterogeneity $\rightarrow CF_{srf}(i)$

CF_{rand}, CF_{max}

For total cloud layer

$CF_{vol,tot} = \sum CF_{srf}(i)$

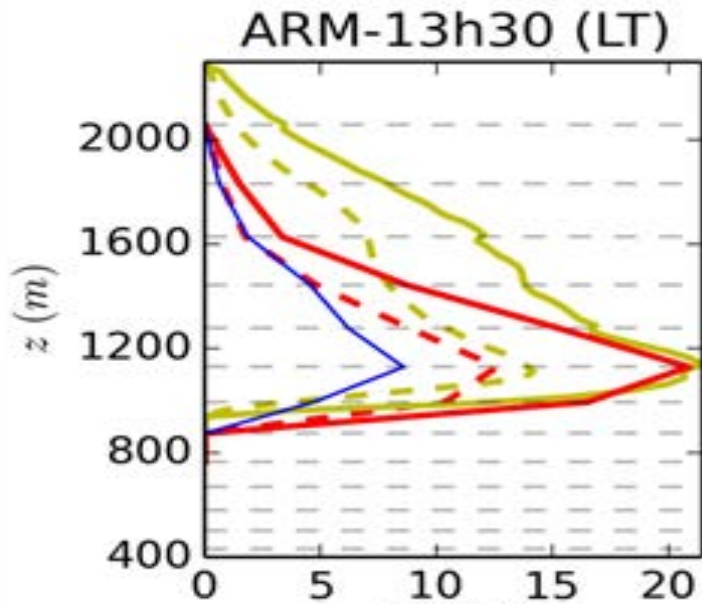
$CF_{srf,tot}$

SG heterogeneity

$$\Delta z_0 = \frac{-\Delta z_{tot}}{\ln \left(\frac{CF_{srf,tot} - CF_{rand}}{CF_{max} - CF_{rand}} \right)}$$

≈ 2 to 5 km

Single column model (SCM)



Cloud fraction(%)

CF_{surf}

CF_{vol}



LES



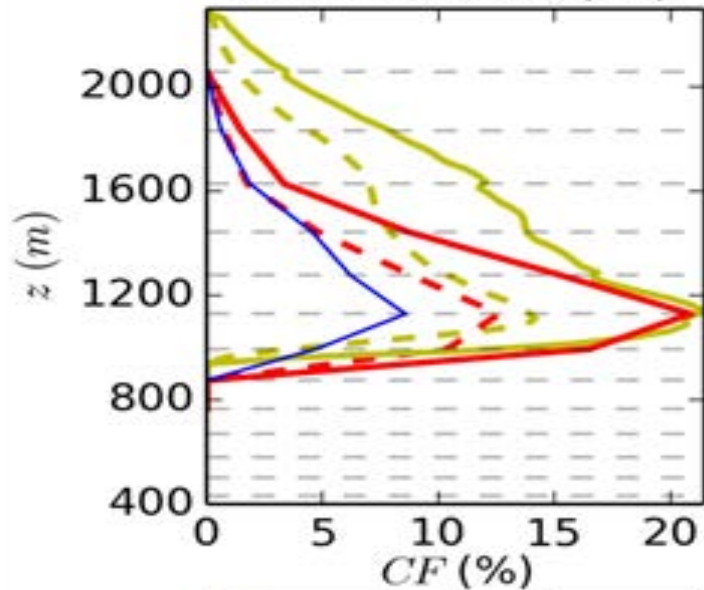
LMDZ5B.x **old**



LMDZ5B.x **new**

Single column model (SCM)

ARM-13h30 (LT)



Cloud fraction(%)

CF_{surf}

CF_{vol}



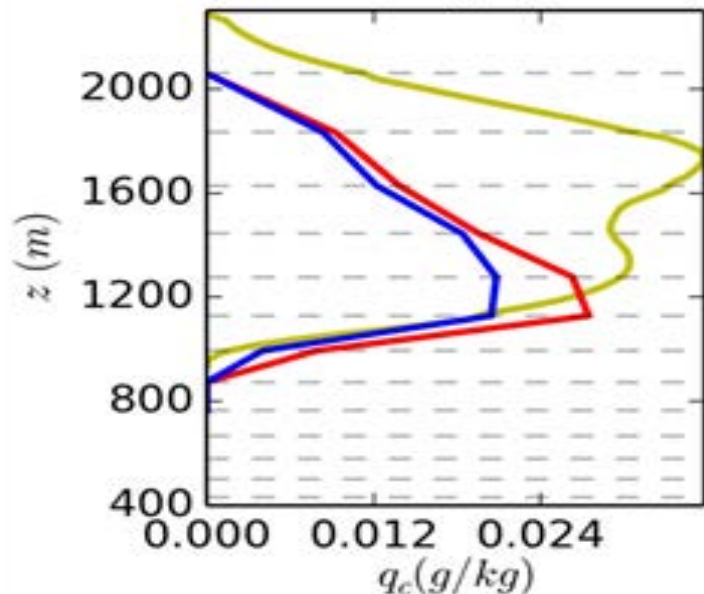
LES



LMDZ5B.x **old**



LMDZ5B.x **new**



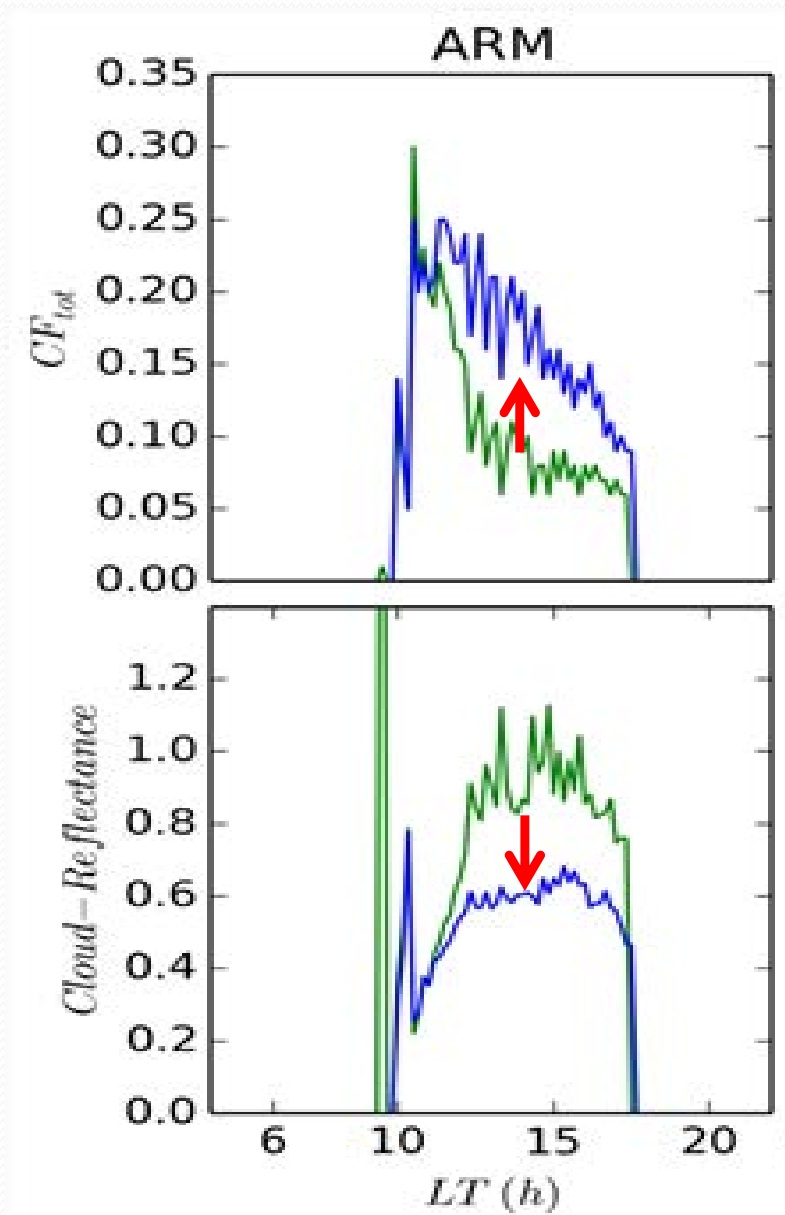
Cloud liquid water content (g/kg)

LES

LMDZ5B.x **old**

LMDZ5B.x **new**

Single column model (SCM)

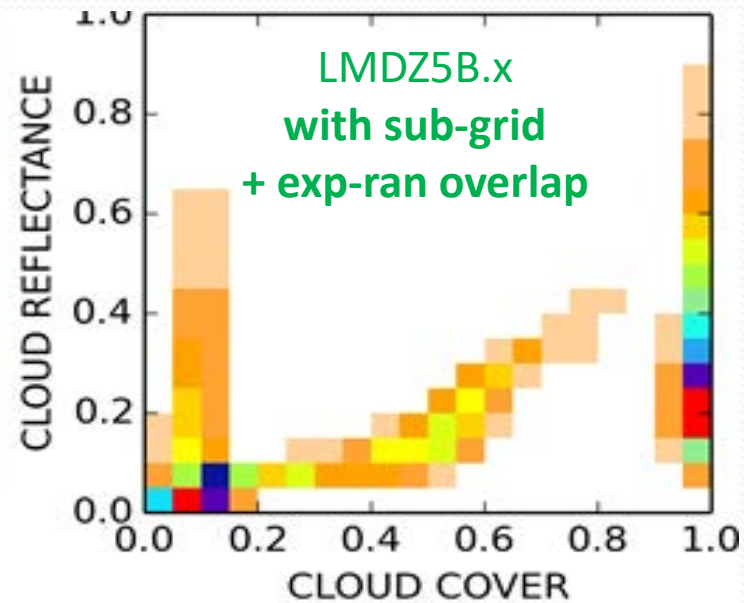
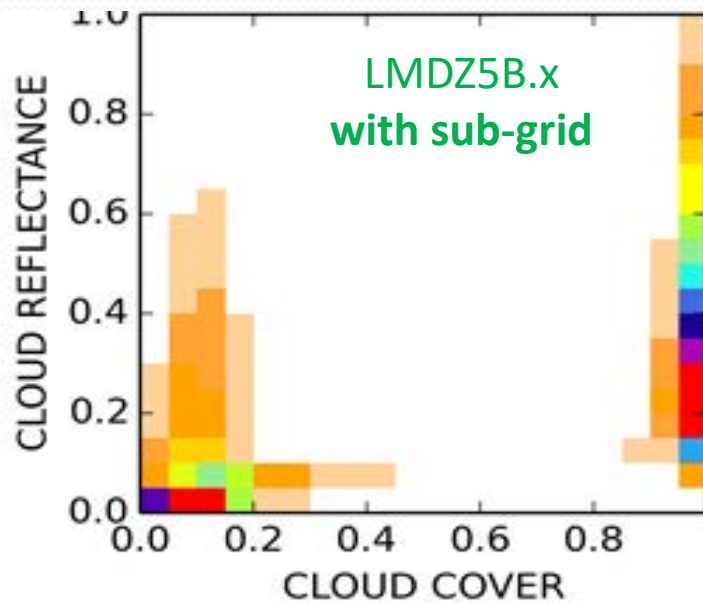
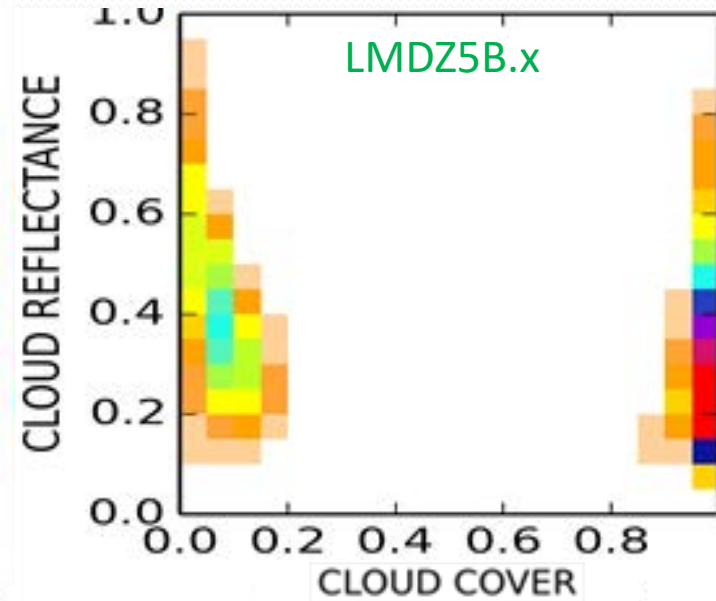
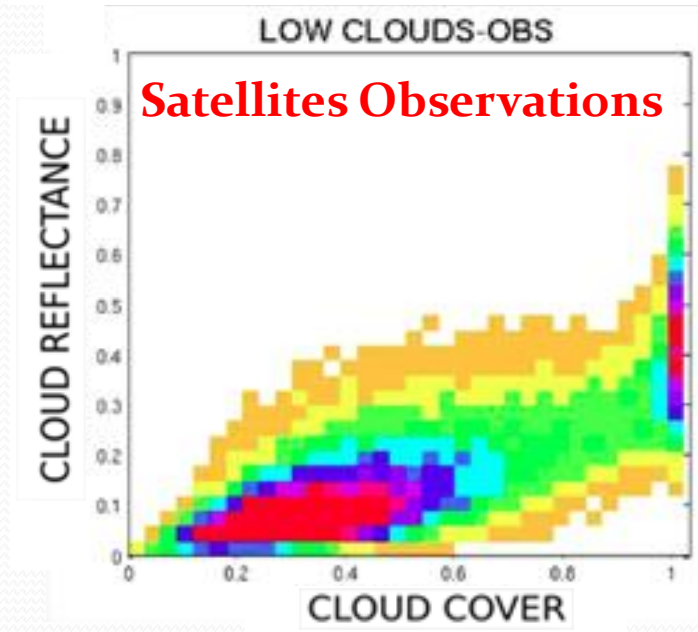


**Cloud fraction
increases**

— LMDZ5B.x **old**
— LMDZ5B.x **new**

**Cloud reflectance
decreases**

3D model, with COSP



More
frequent



Conclusion

- **Cloud vertical heterogeneity** strongly affects the fraction and brightness of low level clouds
- We consider **sub-grid vertical heterogeneity** and **cloud overlap** as two parameterisations of a same phenomena
- These parameterisation **reduces the too few too bright bias**: reflectance of clouds decreases, clouds with intermediate CF (20-50%) are more frequent
- **Cloud macrophysic properties are as important as cloud microphysic**
- Impact on climate sensitivity?
- Extension to high level clouds?